



Davies, D., & MacMillan, F. (2018). Developing Experimental Design and Analysis Skills in Undergraduates. *Advances in Physiology Education*, 42(4), 615-618. <https://doi.org/10.1152/advan.00103.2018>

Peer reviewed version

License (if available):
Unspecified

Link to published version (if available):
[10.1152/advan.00103.2018](https://doi.org/10.1152/advan.00103.2018)

[Link to publication record in Explore Bristol Research](#)
PDF-document

This is the author accepted manuscript (AAM). The final published version (version of record) is available online via APS at <https://www.physiology.org/doi/full/10.1152/advan.00103.2018> . Please refer to any applicable terms of use of the publisher.

University of Bristol - Explore Bristol Research

General rights

This document is made available in accordance with publisher policies. Please cite only the published version using the reference above. Full terms of use are available:
<http://www.bristol.ac.uk/red/research-policy/pure/user-guides/ebr-terms/>

“Developing Experimental Design and Analysis Skills in Undergraduates” IUPS teaching satellite meeting, Brazil August 2017

Dawn Davies and Frances M. MacMillan

School of Physiology, Pharmacology and Neuroscience, Biomedical Sciences Building, University of Bristol. UK. BS8 1TD

Abbreviated title: Developing Experimental Skills in Undergraduates

Key words: Experimental design, Undergraduate, Projects, Analysis skills

Corresponding author: Frances MacMillan

Abstract

This workshop was held at the Teaching Satellite Meeting of the International Union of Physiological Sciences (IUPS) meeting, 5-8th August 2017 in Buzios, Rio de Janeiro, Brazil. The satellite meeting was attended by physiology educators from across the globe of whom 34 attended this workshop. The aim of the workshop was to explore how experimental design is taught to students of physiology in different institutions, to consider the aspects that students find challenging, to share good practice and to think about how experimental design teaching could be improved. Through small group discussions, that were then shared with the whole group, participants were challenged to develop the outline of a research project to investigate a broad topic and then to identify the challenges that students might face if they were given that task. Finally, the group thought about what, in practical terms, could be done to help develop experimental design skills in undergraduates. The outcomes of the discussions are summarised in this report.

Introduction

The development of experimental skills in undergraduate students of Physiology is a key component of their education as defined in the UK by the Quality Assurance Agency for Higher Education (QAA, 9). The QAA define experimental skills not only as the practical competency required to carry out the procedures but also in terms of being able to “design, plan, conduct and report on investigations”, thus highlighting the importance of the experimental design aspect of research. Both academics and students recognise the important transferrable skills gained through activities that include experimental design (6,7,8). Moreover, in a survey on behalf of MathWorks, a mathematics and engineering software developer, both academics and employers cited a lack of project work as a contributing factor in the STEM graduate skills gap in the UK (10). In addition, academics also report that students in their final year are not prepared for their research projects in terms of experimental design, underlining the idea that practicals with a predetermined protocol, or ‘cookbook’ experiments, that are frequently employed in early years of undergraduate degree programs, do not support the development of these skills (1). With this in mind, this workshop was designed as a

forum to discuss the participants' experiences of developing experimental design skills in students with the aim of sharing good practice and generating new ideas to support the development of these skills. At the University of Bristol, UK, we have a progressive programme for the development of experimental design skills through short first and second year experimental design research projects prior to the final year research project, which culminates in a written dissertation/thesis. The workshop conveners were keen to explore the experiences of other educators in terms of the types of project used, the skills required by students to successfully complete these projects and what training is provided for final year undergraduate experimental projects. The groups were tasked with exploring this area of education and considering innovative ways of developing these skills through discussion stimulated by specific questions and tasks.

Structure of workshop

The workshop was attended by 34 participants from across the globe who were attending the Teaching Satellite Meeting of the International Union of Physiological Sciences (IUPS) meeting, 5-8th August 2017 in Buzios, Rio de Janeiro, Brazil. After a short introduction by the workshop conveners, participants were split into groups of approximately 8-10, and questions were posed to stimulate discussion. Groups then shared their main points with all participants for further discussion. The purpose of the first question was to determine what was expected of students at different institutions with respect to experimental design.

Question: What type of projects do your students undertake and what skills do they need?

Types of practical (experimental) projects

It was established that there were many different types of practical projects that undergraduate students may participate in. Whilst the discussion was wide-ranging, the focus was restricted to practical work that had some element of experimental design performed by the students. This

seemed mainly to occur in the final year of undergraduate programmes and culminated in the writing of a thesis or dissertation. The workshop participants indicated that these were mostly longer-term experiments but were on a wide variety of topics. Some topics were what participants referred to as 'classic experimental projects' for example, microscopy, special senses, respiratory physiology and cardiovascular physiology, and others were still perhaps examples of 'classic' physiology but often taking place out of the university laboratory, for example measuring visual acuity in the community and outreach for school children.

Skills needed to complete these projects

Participants identified a wide range of basic skills that students would need to complete projects. Background knowledge of relevant physiology and the literature, as well as a strong foundation in scientific method were key factors. In addition, the participants suggested that, depending on the degree of autonomy they have in designing a project, the students need the following skills in different measures.

Practical skills:

- Time management
- Awareness of financial constraints
- How to deal with difficulties (what to do when something goes wrong or even an appreciation that something might not work as you anticipate)

Critical thinking skills:

- Understanding of controls
- Knowledge of the ethics of experiments
- An understanding of objectives versus outcomes
- Ability to transform ideas into a testable question and from there to design an experiment.

Workshop participants were then challenged with the task of turning an idea into a testable question. Groups were asked to design an experiment based on a very broad question.

Task: Design an experiment to test whether level of exercise influences student wellbeing

There was a lot of lively discussion as groups grappled with identifying a testable question/hypothesis within the ill-defined topic. The title was deliberately chosen to be a familiar concept but very broad to make it a challenge to refine it to a single question.

After initial discussions, the workshop conveners intervened to encourage groups to focus on the following as a starting point for their experimental design:

- What does wellbeing mean and how might you measure it?
- What type of exercise would you focus on?

Participants mainly suggested using questionnaires to score wellbeing as these are reportedly well described in the literature. However, measurement of cortisol levels as an indicator of stress was also proposed. Types of exercise proposed were more varied but generally involved walking, running on a treadmill or stair climbing, an important point being that it had to be controlled to make it internally consistent e.g. intensity/duration. The group discussion also introduced important factors related to controls, for example consideration of baseline levels of fitness determined by VO₂ max and wellbeing scores.

In summary of the discussion, there were many possible ways of approaching this topic, with many measurable parameters; the most important point was to simplify the problem down to a testable question. An example of a testable question proposed at the workshop was:

Does 30 minutes walking per day for 9 weeks affect wellness scores in 18-30 year olds?

The experimental design would include following criteria:

- Wellness - determined by mental health questionnaires
- Exercise - monitored using activity trackers.
- Subjects - two groups: sedentary versus exercise
- Additional controls - baseline fitness measurements would be used to ascertain starting levels of fitness of participants.

Having completed this task the groups were then asked to consider what their students would find difficult about this exercise.

Question: From the students' point of view, what is most difficult about this exercise?

There were aspects of this task that participants found quite challenging, mostly to do with the ill-defined nature of the topic. Participants were asked to put themselves in a student's position and think what they might find difficult. The points raised in discussion could be split broadly into two categories and are summarised in Table 1.

Experimental design	Implementing and analysing the experiment
Narrowing the topic	Coordinating multiple parts of the experiment
Deciding on the groups	Working as a team
Availability of equipment	Dealing with different levels of student engagement
Determining numbers of subjects	Managing time
Standardisation of levels of exercise	Data analysis and interpretation
Defining aims and Objectives	Understanding the literature
Refining the measurements	
Considering bias	

Table 1. Difficulties that might be faced by students when designing an experiment

Discussion then moved on to how educators can help students to develop these skills by posing the following question:

Question: How can we support/train students in early years to help them overcome the difficulties?

It was concluded that students should be exposed to research and the development of experimental ideas early in their degrees, moving away from well defined 'cookbook' experiments in practical classes or at least running these in parallel with experiments that include elements of student led design. Indeed, involvement in research experiences has been identified by undergraduate students

as a benefit in developing research skills (6). The over-arching principle that appeared from the discussion was to allow students the space and time for development of these skills. The outcome of this discussion was some suggestions for structured learning tasks as follows:

- Providing lectures and activities on experimental design focussing on how to ask questions and how to keep experiments simple.
- Reviewing the steps needed before doing an experiment – use experiments in early years to help students identify key components of experimental design.
- Providing statistics training including example or model data at the end of experiments helping students with data analysis and statistics.
- Providing training on understanding experimental ethics
- Undertaking group work to build understanding of experimental design and implementation in student led practicals

Finally, participants were asked to discuss how we assess the skills we want students to acquire.

Question: How can we assess experimental design skills?

Most of the suggestions were those that are already used in some way by educators, for example dissertation/thesis writing, presentation of work in a poster or a talk. Some participants stated that there should be an evaluation of experimental work/practical ability. This is widely used in professional programmes, where students are required to attain competency in specific practical skills and sophisticated software has been developed to support the assessment (3). However, its use has also been described for first year classes within undergraduate science programmes, for example by Moni et al (4), who implemented a scheme of assessing five fundamental experimental skills, including practical ability, within a Human Biology course through direct observation. This could be adapted or expanded to include assessment of the contribution to experimental design via a supervisor's assessment within a final year undergraduate project. One idea that was particularly intriguing was the use of peer feedback through discussions between groups doing different

projects. This formative assessment was described in the workshop as getting groups of students together to present their experimental design and results to each other in an informal setting to encourage sharing of ideas and learning from each other's mistakes. Peer assessment and feedback empowers students with a greater understanding of the criteria upon which judgements of the quality of a piece of work are made. Thus, it has been shown to support 'deep' learning and particularly the development of critical analysis (5). This strategy has been successfully used to assess progress in final year undergraduate research project by peer assessment and feedback on drafts of the dissertation/thesis (2).

Outcomes

This outcome of the discussions generated in this workshop has been to raise awareness and stimulate new thinking around the issue of experimental design teaching. Accordingly, it has stimulated further discussion on how the task of designing an experiment could be incorporated in to an experimental skills unit and the potential for a cross institutional collaboration is actively being pursued.

We were particularly taken by the idea of introducing and then reinforcing the principles of experimental design early in undergraduate programmes. Acting on this idea we have now developed an 'experimental design check list' for our students to complete as part of the pre-lab assessment in their practical classes in the first year. Students will complete this check list following discussion with peers. It will not be formally assessed but following completion students will be presented with a completed form with which they can compare their own submission. This will be introduced in the next academic year via our eBiolabs dynamic on-line manual. eBiolabs is an on-line system used by students to access information about upcoming practical classes and to input, analyse and interpret the results of their experiments. Examples of the practical information and quiz formats can be found on the Community eBiolabs resource, which is accessible to all and free to use (11). Although this proforma will be used in Bristol via eBiolabs it could easily be adapted to a

paper or on-line submission through another platform. This very simple exercise will embed the key concepts in experimental design so that when the students are then required to design their own experimental projects later in the first year they have a familiar framework as a starting point. An example of the checklist, completed for one of our early lab practicals, is shown in Figure 1. The checklist is designed to encourage students to think about fundamental aspects of experimental design but could be adapted to include more challenging concepts as students become more confident. In addition, this exercise could be completed using the primary research papers. The advantage of this would be to also support students' ability to read and understand the scientific literature.

Experimental design check list	
Name of the practical	Collecting physiological data (pulse rate before and after exercise)
What is the experimental question or hypothesis?	What is the effect of exercise on pulse rate?
What are you measuring? Include units (dependent variables)	Pulse rate in beats per minute (bpm)
What are you changing? (independent variables)	Exercise
What are the baseline measurements? (if required)	Pulse rate measurements of subjects taken at rest
How do you know that the results are due to your independent variables? (controlled variables)	Using the same subjects before and after exercise. Ensuring each subject performs the same level of exercise
Are the results qualitative or quantitative?	Quantitative
What type of analysis would you use on the results?	Two tailed paired T test on group data

Figure 1. Example of an experimental design checklist completed for the undergraduate students first physiology laboratory practical on collecting physiological data, in this example, the effect of exercise on pulse rate was investigated.

Conclusion

The discussions within this workshop helped to raise awareness of the critical issues to consider when supporting students in the development of their experimental design skills. The most useful

part of the workshop was observing the development of the discussion around the experimental design task. This prompted participants to think about how to introduce a task on experimental design into their teaching in a more structured way. One idea was the use of an 'experimental design check list'. Through discussion with peers, students complete a proforma to identify the controls, numbers of participants, baseline measurements etc, that would be a starting point necessary for designing an experiment. This would provide an early opportunity for improving the student's experimental design skills.

References

1. Brownell, S., Kloser, M., Fukami, T., Shavelson, R. (2012) Undergraduate biology lab courses: Comparing the impact of traditionally based "cookbook" and authentic research-based courses on student lab experiences. *J. Coll. Sci. Teach.* 41, 36–45.
2. Carnell, B. (2016) Aiming for Autonomy: Formative Peer Assessment in a Final-year Undergraduate Course. *Assessment & Evaluation in Higher Education* 41, 1269–1283.
3. Holmes, D.W., Sheehan, M., Birks, M., Smithson, J. (2018) Development of a competency mapping tool for undergraduate professional degree programmes, using mechanical engineering as a case study, *European Journal of Engineering Education*, 43:1, 126-143.
4. Moni, R.W., Hryciw, D.H., Poronnik, P., Lluca, L.J., Moni, K.B. (2007) Assessing core manipulative skills in a large, first-year laboratory. *Adv in Physiol Edu* 31:3, 266-269
5. Orsmond, P. (2004) Self and Peer Assessment: Guidance on Practice in the Biosciences. *Teaching Biosciences: Enhancing Learning Series*, edited by Maw, S., Wilson, J., and Sears, H. Leeds: Higher Education Academy Centre for Biosciences.
6. Seymour, E., Hunter, A. Laursen, S.L., Deantoni, R. (2004). Establishing the Benefits of Research Experiences for Undergraduates in the Sciences: First Findings from a Three-Year Study. *Sci Ed.* 88:493–534

7. Stefani , L.A.J., Tariq V.-N., Heylings D.J.A & Butcher A.C. (1997) A Comparison of Tutor and Student Conceptions of Undergraduate Research Project Work, Assessment & Evaluation in Higher Education, 22:3, 271-288, DOI: 10.1080/0260293970220302
8. White, H. B., Benore, M. A., Sumter, T. F., Caldwell, B. D. and Bell, E. (2013), What skills should students of undergraduate biochemistry and molecular biology programs have upon graduation? Biochem. Mol. Biol. Educ., 41: 297-301. doi:10.1002/bmb.20729
9. WWW1: <http://www.qaa.ac.uk/en> . Website of the UK's quality body for higher education
10. WWW2: <https://yougov.co.uk/news/2013/10/11/uk-skills-gap-stem-subject/> UK skills gap in STEM subjects
11. WWW:3 <https://www.ebiolabscommunity.org/>. Community eBiolabs lab manual, University of Bristol